

Tumors of the endolymphatic sac in patients with von Hippel–Lindau disease: implications for their natural history, diagnosis, and treatment

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Object. Endolymphatic sac tumors (ELSTs), which often are associated with von Hippel–Lindau (VHL) disease, cause irreversible hearing loss and vestibulopathy. Clinical and imaging surveillance protocols provide new insights into the natural history, mechanisms of symptom formation, and indications for the treatment of ELSTs. To clarify the uncertainties associated with the pathophysiology and treatment of ELSTs, the authors describe a series of patients with VHL disease in whom serial examinations recorded the development of ELSTs.

Methods. Patients with VHL disease were included if serial clinical and imaging studies captured the development of ELSTs, and the patients underwent tumor resection. The patients' clinical, audiological, and imaging characteristics as well as their operative results were analyzed.

Five consecutive patients (three men and two women) with a mean age at surgery of 34.8 years and a follow-up period of 6 to 18 months were included in this study. Audiovestibular symptoms were present in three patients before a tumor was evident on neuroimaging. Imaging evidence of an intralabyrinthine hemorrhage coincided with a loss of hearing in three patients. Successful resection of the ELSTs was accomplished by performing a retrolabyrinthine posterior petrosectomy (RLPP). Hearing stabilized and vestibular symptoms resolved after surgery in all patients. No patient has experienced a recurrence.

Conclusions. Audiovestibular symptoms, including hearing loss, in patients with VHL disease can be the result of microscopic ELSTs. Once an ELST has been detected, it can be completely resected via an RLPP with preservation of hearing and amelioration of vestibular symptoms. Early detection and surgical treatment of small ELSTs, when hearing is still present, should reduce the incidence and severity of hearing loss, tinnitus, vertigo, and cranial nerve dysfunction, which are associated with these tumors.

KEY WORDS • anatomy • endolymphatic sac tumor • pathophysiology • von Hippel–Lindau disease • neurosurgery

ENDOLYMPHATIC sac tumors are histologically benign but invasive tumors that arise from the endolymphatic duct or sac and are located in the posterior petrous bone.^{4,9} Because of their invasive nature, ELSTs frequently cause hearing loss (often sudden and significant), tinnitus, vertigo, aural fullness, and facial nerve dysfunction.¹² Although they can occur sporadically, ELSTs recently have been associated with Online Mendelian Inheritance in Man VHL disease (No. 193300).¹² When identified in patients with VHL disease, ELSTs often occur bilaterally and result

in significant neurological disability, including deafness and dysequilibrium.¹² Despite their potentially devastating effects, the natural history, mechanisms of early symptom formation, and indications for surgical treatment of ELSTs have not previously been determined.

Based on the association of ELSTs with VHL disease,¹² serial high-resolution imaging protocols of temporal bones have been developed that capture the early growth of these tumors and/or tumor-related inner-ear changes in patients who still have hearing. These neuroimaging findings when correlated with clinical studies and operative results provide unique insights into the natural history, mechanisms of symptom formation, and indications for surgery of these lesions. We describe the serial clinical, audiological, neuroimaging, and operative findings in five patients with VHL disease in whom ELSTs developed.

Abbreviations used in this paper: CNS = central nervous system; CT = computerized tomography; ELST = endolymphatic sac tumor; MR = magnetic resonance; RLPP = retrolabyrinthine posterior petrosectomy; VHL = von Hippel–Lindau.

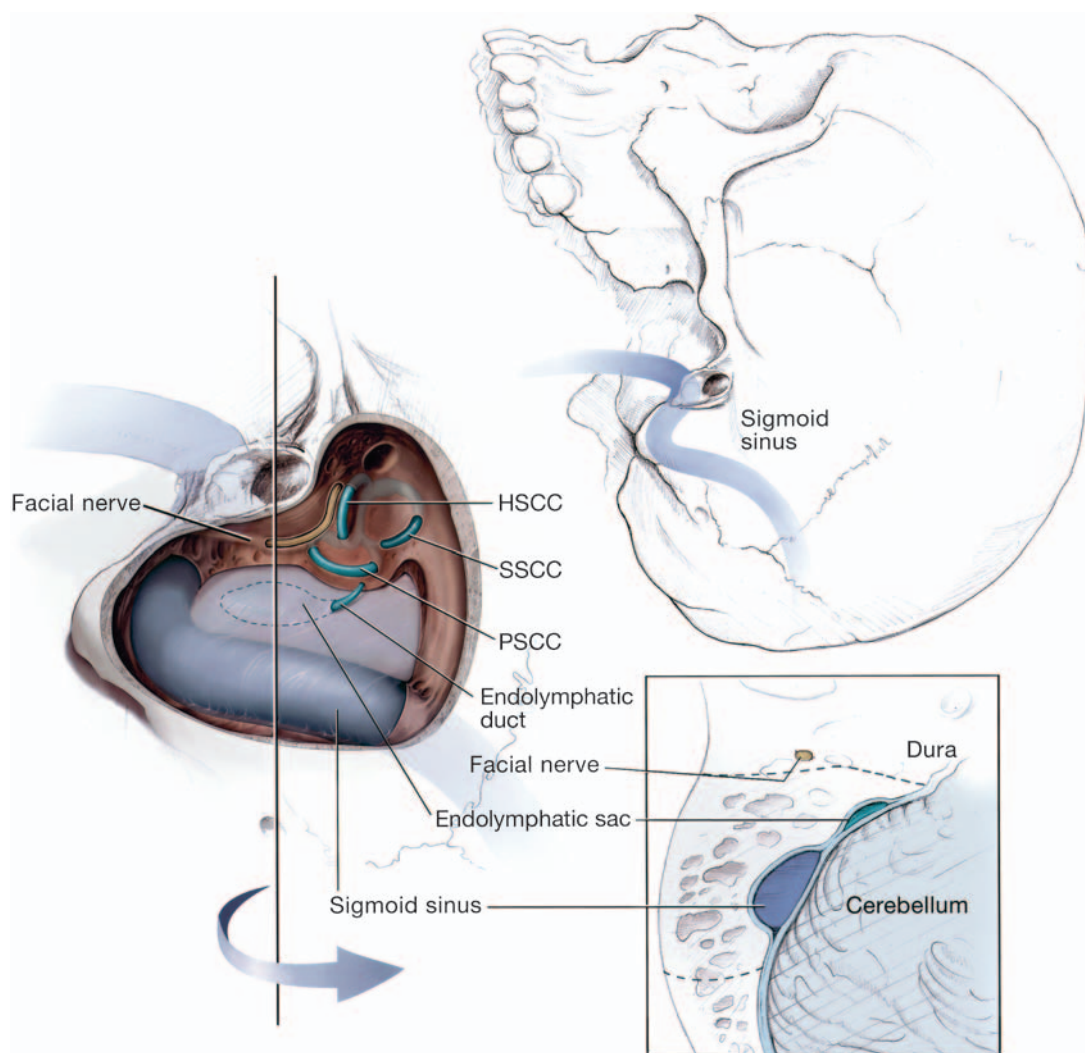


FIG. 1. Schematics demonstrating a lateral view of the anatomical relationships of the normal left posterior petrous bone. Using an RLPP approach, excellent exposure of inner-ear structures including the horizontal, superior, and posterior semicircular canals (HSCC, SSCC, and PSCC, respectively) as well as the facial nerve, endolymphatic duct, and endolymphatic sac can be obtained. *Inset:* Schematic in which the axial plane is indicated by the solid black line demonstrating how the endolymphatic sac is formed by the inner and outer layers of the posterior fossa dura mater as well as the relationship of this sac to the facial nerve, sigmoid sinus, and cerebellum. Dashed lines in the inset show the extent of bone removal in the axial plane when performing the RLPP.

Clinical Material and Methods

Patient Population

This study focuses on five patients with VHL disease who were examined at the National Institutes of Health with the aid of serial clinical and imaging studies that captured the development of ELSTs and who underwent tumor resection.

Patient Examinations

Clinical Examination. Serial neurootological examinations were conducted in patients before and after surgery (at ~ 6–12-month intervals). Data obtained from inpatient charts, clinical notes, audiograms, and operative reports were recorded.

Neuroimaging Studies. Patients were examined pre- and postoperatively with the aid of serial high-resolution, T_1 -weighted (before and after administration of a contrast agent), T_2 -weighted, fluid-attenuated inversion recovery, and spoiled-gradient MR imaging. The largest diameter of the tumor measured on MR images was recorded. Patients were also evaluated pre- and postoperatively with the aid of serial high-resolution CT scanning of temporal bones.

Surgical Technique

In cases such as these we use an RLPP approach for tumor resection, which has been modified from a similar approach described by Megerian, et al.¹³ The approach we follow provides an excellent exposure of the specific anatomical structures (Fig. 1) necessary for complete ELST

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resection (such as the posterior petrous bone, the endolymphatic sac, and the endolymphatic duct).

Intraoperative Monitoring. Facial nerve monitoring is performed during tumor resection. Intraoperative monitoring of brainstem auditory evoked responses is performed if preoperative serviceable hearing is present.

Positioning and Incision. The patient is placed supine, anesthesia is induced, and intubation is performed. The patient's head is slightly extended at the neck and turned 70 to 80° away from the side of surgery (Fig. 2). Hair in the posterior auricular region is shaved and the scalp is prepared and draped in a sterile fashion. An extended posterior auricular incision is made.

The RLPP. Using a high-speed drill, a cortical mastoidectomy is performed (Figs. 2 and 3) over the Macewen triangle. The tegmen and sigmoid sinus are identified superiorly and posteriorly, respectively (Fig. 3). The sigmoid sinus and the jugular bulb (including the posterior sinodural angle) are skeletonized. The horizontal semicircular canal is identified, and the vertical segment of the facial nerve is delineated from its external genu near the horizontal semicircular canal superiorly to the stylomastoid foramen inferiorly. The bone between the sigmoid sinus and the bony labyrinth is removed to expose the underlying posterior fossa dura mater. Once the posterior semicircular canal has been delineated, the endolymphatic sac is identified within the posterior fossa dura below the Donaldson line (Fig. 3), and the endolymphatic duct is identified inside the bony vestibular aqueduct. The bony operculum that forms the posterior limit of the vestibular aqueduct is removed so that the endolymphatic duct can be made visible as it enters the inner ear. Typically, the center of smaller ELSTs is encountered at the distal portion of the endolymphatic duct, as it fans outward to form the endolymphatic sac between the anterior and posterior leaflets of the posterior fossa dura (Fig. 1). The endolymphatic duct is removed en bloc (Fig. 4). The petrous bone and air cells adjacent to and involved with the tumor are drilled out until normal bone is encountered. The posterior fossa dura including and surrounding the endolymphatic sac is resected so that a clear margin around the tumor and sac can be obtained.

Closure. The antrum is sealed with fascia and adipose tissue. The posterior fossa dural defect and the mastoid cavity are filled with layers of abdominal fat and fibrin glue (Fig. 4). The wound is closed in multiple layers.

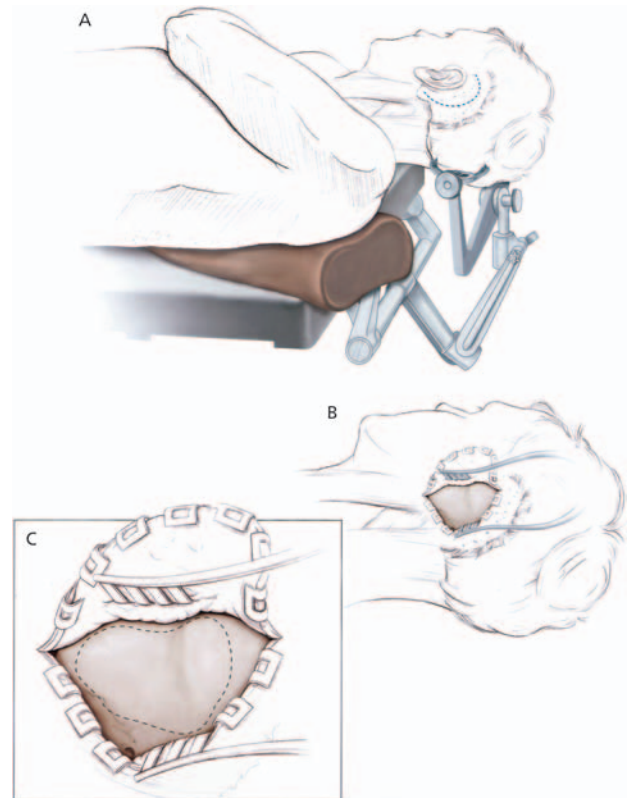


FIG. 2. A: Schematic demonstrating the position of the patient and the incision (dashed line) used for a left-sided RLPP for resection of an ELST. B: View of the skin opening and bone exposure used for the RLPP. C: Magnified view of the bone exposure and the outline (dotted line) of the cortical mastoidectomy for the RLPP, which begins over the Macewen triangle whose borders are the external auditory meatus, the inferior temporal line, and the suprameatal line (spine of Henle) at the upper superoposterior angle of the external auditory meatus.

Results

Patient Characteristics

Five consecutive patients with VHL disease (three men and two women) in whom ELSTs developed during serial examinations and who underwent resection were identified (Table 1). The mean age of these patients at surgery was

TABLE 1
Summary of characteristics in five patients who underwent resection of ELSTs

Case No.	Age (yrs), Sex	Tumor Side	Tumor Diameter (mm)*	Preop Symptoms†	Postop Results	Follow Up (mos)
1	42, M	lt	5	hearing loss (SRT 60 dB), vertigo, & tinnitus	stable hearing, resolution of vertigo, & tinnitus	18
2	40, M	lt	19	hearing loss (SRT 35 dB), vertigo, tinnitus, & aural fullness	stable hearing, resolution of vertigo, tinnitus, & aural fullness	18
3	27, F	lt	11	temporary mild hearing loss (SRT 25 dB) & vertigo	stable hearing & resolution of vertigo	12
4	34, F	lt	3	hearing loss (SRT 40 dB), vertigo, tinnitus, & aural fullness	stable hearing, resolution of vertigo, tinnitus, & aural fullness	12
5	31, M	lt	7	vertigo	stable hearing & resolution of vertigo	6

* Based on the largest diameter measured on MR images at the time of surgery.

† Audiogram speech reception threshold (SRT) hearing loss in decibels immediately before resection.

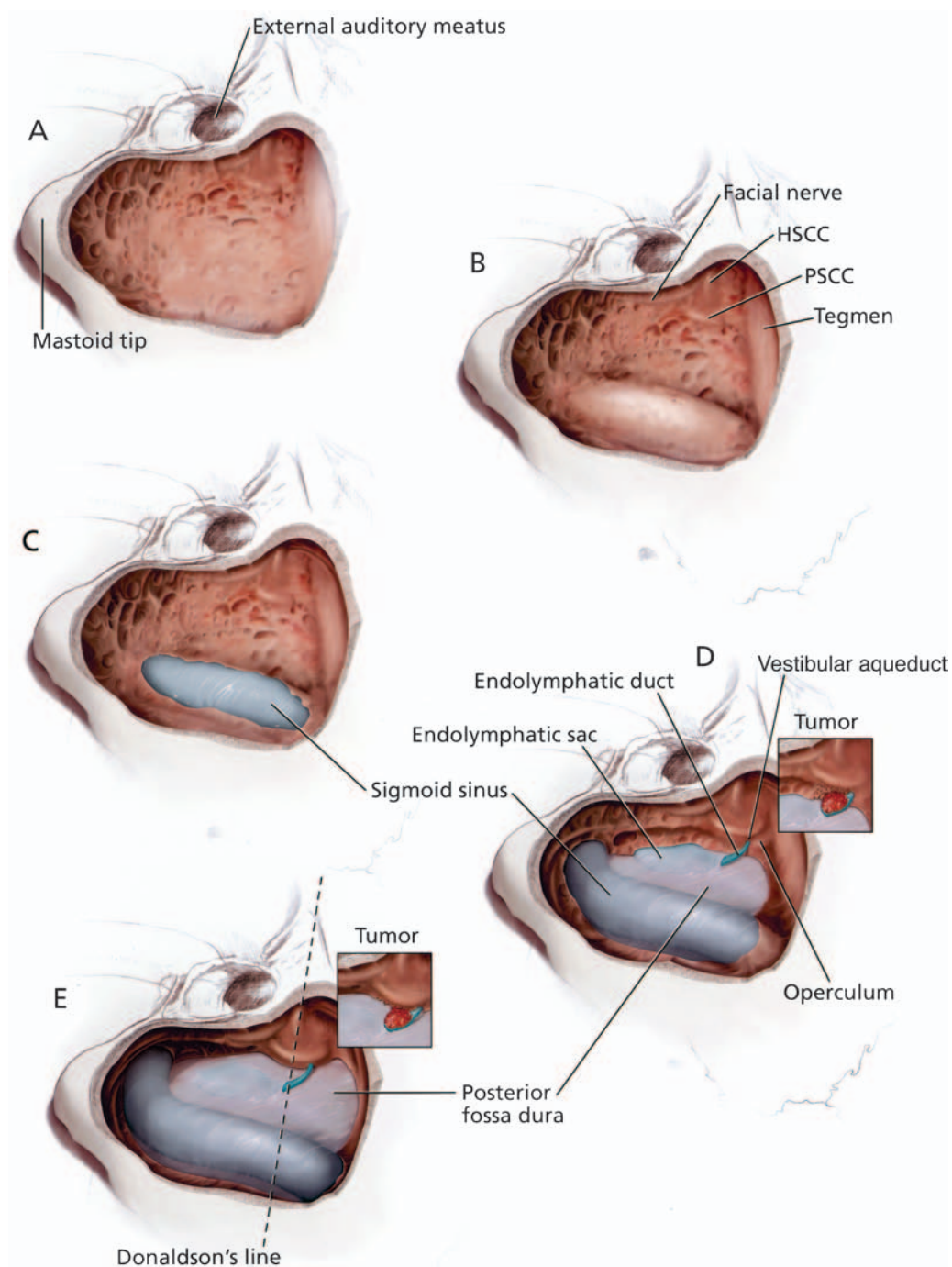


FIG. 3. Illustrations of the microsurgical exposure of a small left-sided ELST performed using an RLPP. A: A cortical mastoidectomy is started over the Macewen triangle. B and C: The mastoidectomy is made deeper to expose the tegmen superiorly and the sigmoid sinus posteriorly. The bone canal over the vertical segment of the facial nerve is skeletonized from the external genu of the nerve near the horizontal semicircular canal superiorly to the stylomastoid foramen inferiorly. The bone canal over the posterior semicircular canal is exposed as the mastoid air cells are drilled away medially. D: The mastoid bone and air cells between the sigmoid sinus and the bone labyrinth are removed to expose the underlying posterior fossa dura mater, including the sinodural angle. The endolymphatic duct is identified inside the vestibular aqueduct. The center of the hypervascular ELST (*inset*) is typically encountered at the distal portion of the endolymphatic duct as it fans outward to form the endolymphatic sac between the anterior and posterior leaflets of the posterior fossa dura. E: The bone operculum, which lies medioposterior to the vestibular aqueduct, is removed (*inset*) further exposing the tumor and the endolymphatic duct. The location of the endolymphatic sac is identified within the posterior fossa dura at the Donaldson line (*dashed line*), which runs parallel to the horizontal semicircular canal and perpendicular to the posterior semicircular canal.

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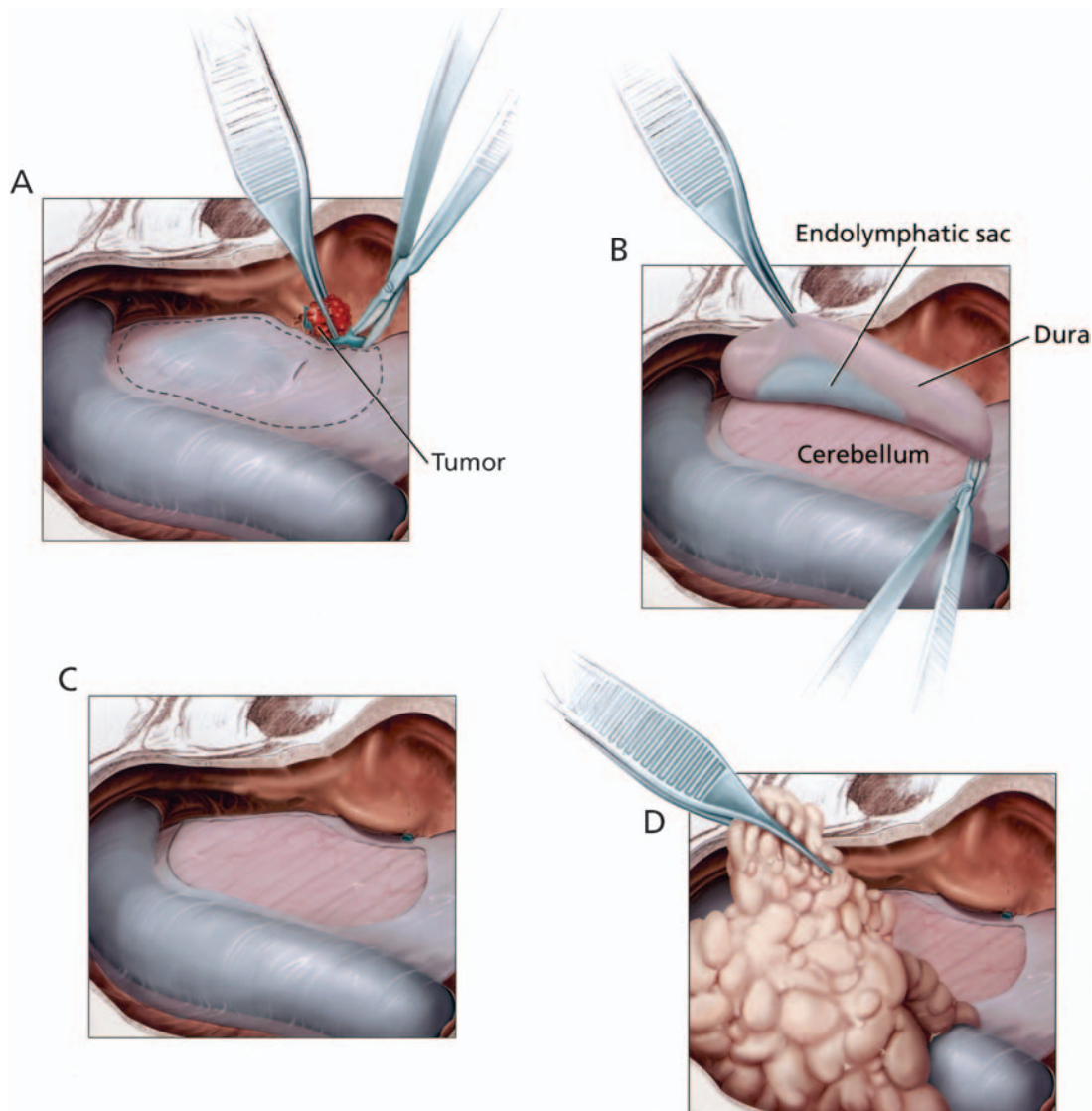


FIG. 4. Illustrations demonstrating the microsurgical removal of a small ELST. A: Once the ELST has been identified with the involved portion of the endolymphatic duct (see Fig. 5), the lesion is removed en bloc with the involved duct. Because ELSTs commonly cause bone erosion around the endolymphatic duct, once the duct and tumor have been removed, the petrous bone and the air cells adjacent to the tumor are drilled out until normal bone is encountered. B and C: The posterior fossa dura is resected to obtain a clear margin around the tumor and the endolymphatic sac (dashed line in A) while preserving the underlying posterior fovea arachnoid layer. D: After removal of the ELST and the endolymphatic sac, the mastoid cavity is filled with abdominal fat and the wound is closed in layers.

34.8 years (range 27–42 years), and the mean follow-up period after resection was 13.2 months (range 6–18 months). In all five patients there was imaging evidence of a left-sided ELST with a mean tumor diameter of 9 mm (range 3–19 mm). Portions of the clinical findings obtained in two of these patients (Cases 1 and 4; Table 1) have been presented in a previous report.⁹

Clinical Findings

All five patients presented with vestibulocochlear symptoms (Table 1), and all had episodic vertigo. In four of these patients (Cases 1–4) the vertigo responded to steroid (prednisone) therapy; in the other patient (Case 5) steroid agents

were not used and the vertigo resolved spontaneously after 21 days. Three patients (Cases 1, 2, and 4) experienced worsening of their tinnitus, which coincided with episodes of vertigo; the tinnitus was similarly improved with steroid therapy. In two patients (Cases 2 and 4) aural fullness was one of the audiovestibular symptoms.

Three patients experienced sensorineural hearing loss before surgery (Cases 1, 2, and 4; Table 1). The onset of hearing loss in these patients also coincided with an attack of vertigo. The hearing loss progressed in a stepwise manner in these patients and occurred over 12 (Case 4) or 24 (Cases 1 and 2) months. One patient (Case 3) exhibited mild temporary low-frequency hearing loss 3 months before resection, which was associated with vertigo. The hearing loss

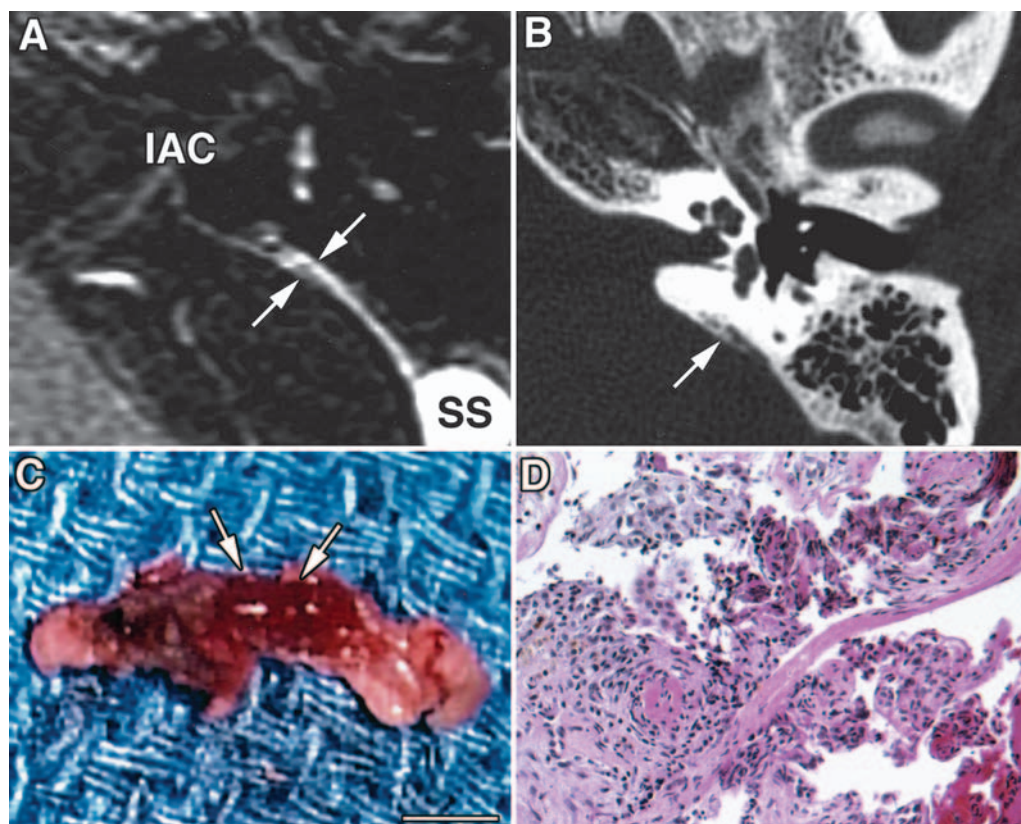


FIG. 5. Case 1. A: Preoperative axial contrast-enhanced MR image of the left posterior petrous region demonstrating a small enhancing lesion in the left endolymphatic sac (arrows), which is formed by the inner and outer leaves of the posterior fossa dura and located between the internal auditory canal (IAC) and the sigmoid sinus (SS). B: Corresponding preoperative axial nonenhanced CT scan of the left temporal bone demonstrating bone erosion in the region of the endolymphatic sac (arrow). C: Photomicrograph of excised tissue. During the resection, the endolymphatic duct (red-tan tissue) was removed en bloc and opened, revealing gross evidence of the ELST with hemorrhage (raspberry-colored lesion, arrows). Bar = 1 mm. D: Photomicrograph of tissue sample. The histological study confirmed the diagnosis of an ELST. H & E, original magnification $\times 20$.

and vertigo resolved in response to oral steroid therapy (a 21-day course of prednisone).

Neuroimaging Findings

In all five patients there was neuroimaging evidence of an ELST at the time of surgery, including enhancement of the lesion on MR images, and findings of bone erosion in the region of the endolymphatic sac and/or duct on CT scans (Fig. 5). In two patients (Cases 3 and 5; Table 1) there was neuroimaging evidence of an ELST before onset of audio-vestibular symptoms. In the other three patients (Cases 1, 2, and 4) audiovestibular symptoms, including tinnitus (all three cases), vertigo (Case 1), and aural fullness (Case 2), developed before imaging evidence of an ELST was present. Later (1–2 years after onset of the audiovestibular symptoms) these three patients experienced permanent sensorineural hearing loss, which coincided with the development of an intralabyrinthine hemorrhage seen on MR images (Fig. 5). At the time of the intralabyrinthine hemorrhage, neuroimaging evidence of an ELST was discovered in two of these patients (Cases 1 and 2), but was not seen until 1 year after hemorrhage in the third patient (Case 4).

Surgical Findings

The RLPP approach provided excellent exposure of each ELST, the endolymphatic duct and sac, and the surrounding anatomy. The ELSTs appeared to be vascular lesions that arose from the distal endolymphatic duct (Fig. 5) and/or the proximal endolymphatic sac, and eroded the immediately adjacent temporal bone. Gross tumor was found in both the endolymphatic duct and sac in four patients (Cases 1–3 and 5; Table 1), but was confined to the endolymphatic duct and the immediately surrounding temporal bone in one patient (Case 4).

Surgical Outcome

Removal of the tumors resulted in preservation of hearing (same level of hearing as measured preoperatively on audiograms). All patients experienced alleviation of their audiovestibular symptoms including vertigo, tinnitus, and aural fullness. There was no evidence of recurrence in any patient. One patient (Case 1; Table 1) had a wound infection 4 weeks after resection. He was successfully treated with cranioplasty removal and a course of antibiotic agents. The

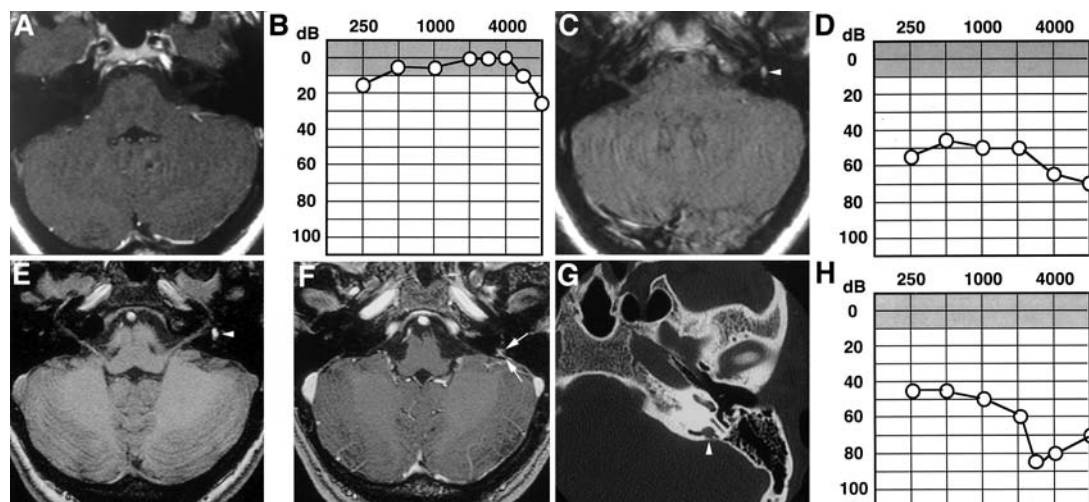


FIG. 6. Case 4. Serial MR and CT images of the temporal region and corresponding audiograms (contemporaneously performed with the neuroimaging) demonstrating the development of a left ELST and associated hearing loss. A: Contrast-enhanced T₁-weighted MR image obtained in 2000, demonstrating no evidence of an ELST despite the onset of left tinnitus. B: Audiogram obtained at that time, displaying normal findings for a slight high-frequency hearing loss. Worsening tinnitus developed and was associated with acute left-sided hearing loss and vertigo in 2002. C: Axial nonenhanced T₁-weighted MR image revealing an intralabyrinthine hemorrhage (arrowhead) on the left side, but no evidence of an enhancing tumor. D: Audiogram revealing a moderate left-sided sensorineural hearing loss. In 2003, the patient experienced worsening left-sided hearing loss, while continuing to have left-sided tinnitus and vertigo. Axial T₁-weighted nonenhanced (E) and contrast-enhanced (F) MR images again revealing evidence of an intralabyrinthine hemorrhage (arrowhead in E) as well as an enhancing lesion in the region of the left endolymphatic duct (arrow in F). G: Corresponding axial nonenhanced CT scan of the left temporal bone demonstrating bone erosion in the region of the left endolymphatic duct (arrowhead). H: Audiogram revealing progressive moderate-to-severe sensorineural hearing loss on the left side.

histological study confirmed the diagnosis of ELST in each case (Fig. 5).

Illustrative Case

Case 4

History. This 34-year-old woman received the diagnosis of VHL in 2003. Her audiological symptoms had begun in 2000 when she had experienced intermittent left tinnitus. Findings on MR images of the temporal bones were normal (Fig. 6). In 2002, her tinnitus worsened and was associated with vertigo and acute hearing loss. Magnetic resonance imaging revealed a left-sided intralabyrinthine hemorrhage, but no evidence of tumor. In 2003, she was referred to the National Institutes of Health for further examination.

Examination. The patient suffered acute hearing loss and aural fullness, which had appeared during the previous month and was associated with worsening tinnitus and vertigo. She was neurologically intact except for a left-sided hearing loss. Magnetic resonance images revealed evidence of an intralabyrinthine hemorrhage and a small (3-mm) enhancing lesion located in the left endolymphatic duct. Computerized tomography scans revealed erosion of the posterior petrous bone in the region of the endolymphatic duct. An audiogram obtained 1 day before surgery revealed a moderate (low-frequency range) to severe (high-frequency range) left-sided sensorineural hearing loss (Fig. 6).

Operation. The patient underwent ELST resection via a left RLPP (see *Surgical Technique*). A small ELST originat-

ing from the distal portion of the endolymphatic duct was removed. The ELST, the endolymphatic duct, and the anterior dural leaflet of the endolymphatic sac were removed in one piece. The posterior dural leaflet was excised separately. A histological study confirmed the diagnosis of ELST.

Postoperative Course. After surgery, the patient reported resolution of her tinnitus and vertigo. An audiogram obtained after surgery revealed stable functional hearing (same as the preoperative level). Postoperative CT scans confirmed complete resection of the tumor (duration of the follow-up period was 12 months).

Discussion

Endolymphatic Sac Tumors in Patients With VHL Disease

Von Hippel–Lindau disease is an autosomal-dominant neoplastic disorder that is caused by a germline mutation in the *VHL* gene on chromosome 3.⁵ Von Hippel–Lindau disease has a prevalence of one in 39,000 persons.¹⁵ Patients with VHL disease are predisposed to the development of benign and/or malignant visceral and CNS lesions. Visceral features include renal cell carcinomas and cysts, pheochromocytomas, pancreatic neuroendocrine tumors, and reproductive adnexal organ cystadenomas.⁸ Tumors of the CNS include hemangioblastomas of the retina, cerebellum, brainstem, spinal cord, and nerves, as well as ELSTs.^{8–12,16,17}

Despite the description of an erosive petrous bone lesion in the first such patient treated by Eugene von Hippel and a

patient treated by Arvid Lindau⁶ as well as sporadic reports of ELSTs in patients with VHL disease, ELSTs were only recently established as part of the VHL neoplastic syndrome.^{1,12} Although these tumors rarely occur in the general population, they are frequently found in patients with VHL disease with the aid of MR or CT imaging, and their incidence has been reported to range between 11 and 16%.^{2,12} Von Hippel-Lindau disease is the only condition that has been identified to be associated with bilateral ELSTs. Endolymphatic sac tumors have been found to occur bilaterally in approximately 30% of patients with VHL disease who harbor these tumors.^{12,13}

Patients with VHL disease in whom there is imaging evidence of an ELST present with hearing loss (95–100%), tinnitus (92%), vertigo or dysequilibrium (62%), aural fullness (29%), and facial paresis (8%), which can be attributed to the imaged lesion.^{2,12} Hearing loss associated with imaging-evident ELSTs has been reported to occur suddenly and in a clinically significant manner (43%) or in a stepwise progressive manner (43%) over a 3- to 6-month period.^{2,12} Occasionally, patients (14%) have reported a more insidious or gradual hearing loss.^{2,12} Generally, once hearing loss occurs it is irreversible, and it tends to occur early in life (mean age at the onset of hearing loss is 22 years).¹²

Current Study

Clinical Findings. Similar to previous reports,^{2,12} all five of our patients presented with vestibulocochlear symptoms (Table 1) and all had episodic vertigo. In four patients vertigo was successfully treated with steroid therapy; in the fifth the vertigo resolved spontaneously. Three patients experienced sensorineural hearing loss before surgery and the onset of hearing loss in these patients coincided with an attack of vertigo. The hearing loss followed a stepwise progression in these patients and occurred over a period of 12 to 24 months. Three patients had tinnitus that coincided with episodes of vertigo; their symptoms were similarly relieved with steroid therapy. Two patients had complaints of aural fullness as part of their audiovestibular symptoms.

Neuroimaging Findings. In all patients there was neuroimaging evidence of an ELST at the time of surgery including enhancement of the tumor on MR images, and bone erosion in the region of the endolymphatic sac and/or duct seen on CT scans.^{7,14} Three patients experienced audiovestibular symptoms before imaging evidence of tumor or an inner-ear abnormality was seen. This indicates that microscopic tumors may be the underlying cause of symptoms in some patients with VHL disease without evidence of ELST. Findings consistent with intralabyrinthine hemorrhage were later seen on MR images in these three patients and coincided with hearing loss. These observations indicate that acute intralabyrinthine hemorrhage by the tumor may be an early neuroimaging indicator of the presence of an ELST in patients with VHL disease.^{3,12}

Based on these findings, serial clinical and imaging studies obtained in patients with VHL disease that capture the early development of ELSTs and permit their prompt diagnosis are critical. Currently, we perform serial high-resolution nonenhanced and contrast-enhanced MR imaging (fluid-attenuated inversion-recovery, spoiled-gradient, T₁-weighted, and T₂-weighted sequences) and CT scanning

of temporal bones to detect small ELSTs, intralabyrinthine hemorrhage, and/or bone erosion (in the region of the endolymphatic sac) in all patients with VHL disease. These studies are obtained at routine CNS screening intervals (1–2 years) or when audiovestibular symptoms arise.⁸ Audio-logical studies are performed in conjunction with routine CNS examinations and the development of audiovestibular symptoms.

Intraoperative Findings. Intraoperatively, the ELSTs appeared to arise from the distal endolymphatic duct and/or the proximal endolymphatic sac. The gross appearance of tumor in the endolymphatic sac in most patients (four of five patients) indicates that the dura mater investing the sac should be resected with the tumor to achieve a complete removal and prevent recurrence. Because the endolymphatic sac is a potential space between the inner and outer layers of the dura mater, its precise borders may be difficult to ascertain during surgery. We routinely remove at least a 2-mm border of dura around the endolymphatic sac if the anatomy permits (for example, position of the venous sinuses).

Surgical Results. The RLPP approach provides excellent access to the endolymphatic duct, endolymphatic sac, and posterior petrous region. Complete resection of ELSTs was curative and resulted in preservation of hearing, emphasizing the importance of early intervention to prevent an additional decline in hearing. In all patients vestibular symptoms were alleviated after removal of the tumors. There was no evidence of recurrence in any patient.

Mechanism of Symptom Formation

Despite previous reports that correlate large imaging-evident ELSTs (particularly tumors invading the otic capsule) and symptoms, a significant fraction (59%) of patients with VHL disease and vestibulocochlear symptoms have no imaging evidence of ELSTs.¹² The underlying cause of these symptoms is not completely defined. Based on the cases presented here we can surmise that the cause of these clinical manifestations, in at least some patients, is a microscopic ELST. This is consistent with the initial lack of imaging evidence of the tumor at symptom onset, but the development of an imaging-evident ELST later in the clinical course of patients in Cases 1, 2, and 4 (Table 1).

Acute intralabyrinthine hemorrhage may explain the frequent occurrence of irreversible, acute, and significant hearing loss that occurs frequently in patients with ELSTs. This is supported by hemosiderin in the utricular macula of the inner ear of a patient with VHL disease and a microscopic ELST discovered at autopsy,⁹ MR imaging evidence of intralabyrinthine hemorrhage coinciding with acute hearing loss, and hemorrhage in resected tumors. The frequent irreversibility of symptoms (particularly hearing loss) in these patients may result from cochlear and/or neuronal degeneration after hemorrhage and/or secondary inflammation.⁹

Histological evidence of hydrops in the temporal bone in the setting of ELST may also explain the Ménière disease-like clinical syndrome (hearing loss, tinnitus, and vertigo) that affected these and other patients with ELST.⁹ Hydrops may result from a blockage of endolymphatic sac resorption of endolymph, inflammation in response to hemorrhage, and/or excessive production of fluid by the tumor. The pro-

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duction of peritumoral fluid by ELSTs would be analogous to the formation of peritumoral edema and cysts that are frequently associated with CNS hemangioblastomas and visceral tumors in patients with VHL disease.^{8,11,16,17}

The RLPP Approach for Resection of ELSTs

To remove ELSTs completely and minimize the possibility of recurrence, we routinely remove the endolymphatic sac and involved duct. The RLPP approach is ideal because it consistently provides an excellent view of and access to these anatomical structures. Unless there are abundant mastoid air cells between the otic capsule and the posterior fossa dura, a transmastoid approach will not allow adequate exposure of the endolymphatic sac and duct. In contrast, during an RLPP the endolymphatic sac and duct can be completely delineated behind the posterior semicircular canal once the bone over the sigmoid sinus and posterior fossa has been removed and retracted away. The tumor can then be safely removed while tracing the endolymphatic duct proximally into the inner ear and making visible the limits of surrounding inner-ear structures. The RLPP also provides an excellent exposure of the petrous apex and jugular bulb via the retrofacial air cells. Because ELSTs commonly extend toward the petrous apex and to the jugular bulb as they enlarge, it is often necessary to have access to these regions when resecting larger tumors near these structures.

A retrosigmoid approach for ELST resection, as described by Megerian, et al.,¹³ has also been used to remove ELSTs. The retrosigmoid approach alone may be suboptimal because it can be difficult to delineate the entire posterior semicircular canal and endolymphatic duct from the posterior fossa side safely, it is associated with a higher risk for a cerebrospinal fluid leak via the exposed mastoid air cells, and it may require dissection through postoperative scar tissue, which is found frequently in patients with VHL disease (that is, those who have previously undergone posterior fossa craniotomies for hemangioblastoma removal). To provide increased exposure, however, the retrosigmoid approach may be combined with an RLPP when the ELST extends to the internal auditory canal, into the cerebellopontine angle, and/or to the petrous apex medial to the internal auditory canal in patients with serviceable hearing. Patients who have no useful hearing and harbor large ELSTs (that is, those with extensive temporal bone involvement and extension into the cerebellopontine angle) should undergo a combined retrosigmoid–translabyrinthine or transotic approach for resection.

Surgical Indications

The indications for tumor resection must be based on the ability to cure these tumors surgically while preserving vestibulocochlear function. The cases presented here demonstrate that hearing loss and vestibular symptoms can occur with small tumors that do not invade the otic capsule. Thus, the mechanism of vestibulocochlear symptom formation in patients with small ELSTs (those not invading the otic capsule and confined to the lateral temporal bone) appears to be related to tumor-associated hemorrhage and/or hydrops and not to tumor size.⁹ Because small ELSTs can be successfully resected with hearing preservation, and because symptom formation is not linked to tumor size and is unpredict-

able, it may be reasonable to resect these neoplasms before they produce audiovestibular deficits. Thus, we propose that patients with imaging evidence of ELST require surgery to prevent audiovestibular morbidity. Patients without hearing who have imaging evidence of an ELST should undergo resection if neurological compromise or compression are present or clinical signs or symptoms are evident. Because intralabyrinthine hemorrhage may be an indicator of a microscopic ELST in patients with VHL disease, patients who retain their hearing and have a lack of imaging evidence of ELST but evidence of intralabyrinthine hemorrhage on imaging are also candidates for surgical intervention.

Conclusions

Preservation of audiovestibular function in individuals affected by VHL disease is critical to prevent the potential combined effects of vision loss, imbalance, and hearing loss, which can occur in this syndrome. Routine serial surveillance and refined imaging techniques now permit the frequent detection of small ELSTs in patients with VHL disease who still have hearing. Once ELSTs are detected, they can be successfully resected by means of an RLPP with preservation of hearing and amelioration of vestibular symptoms. Subsequently, early detection and resection should reduce the incidence and severity of hearing loss, tinnitus, vertigo, and cranial nerve dysfunction in patients with these tumors.

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